A comment on *"A semiconductor source of entangled photons"*

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Abstract

When basic tools of quantum information are applied to the quantum tomography data presented in [1], none of their devices appears to be a source of entangled photons.

In a paper titled *"A semiconductor quantum source of triggered entangled photon pairs"* Stevenson *et. al.* [1] claim to find evidence for the emission of polarization entangled photons from certain quantum dots.

A density matrix completely specifies all properties of the quantum state [2]. Using quantum tomography [3], the authors of [1] construct the density matrices representing the polarization state of the photons emitted by each of their devices. We show that subjecting their quantum states to the basic definition of entanglement leads to the inevitable conclusion that none of their devices produced entangled light.

In all the dots investigated in [1], quantum tomography yielded real density matrices of the form

$$\rho = \begin{pmatrix} \alpha & 0 & 0 & \gamma \\ 0 & \beta & 0 & 0 \\ 0 & 0 & \beta' & 0 \\ \gamma & 0 & 0 & \alpha' \end{pmatrix}, \tag{1}$$

with $\beta \approx \beta'$ and the zeros stands for terms that are comparable to the measurements' noise. (The matrix is written in the basis $\{|HH\rangle, |HV\rangle, |VH\rangle, |VV\rangle\}$.)

A straightforward test for entanglement is the Peres separability criterion [4]. For the matrix ρ of Eq. (1), (we set $\beta = \beta'$ for simplicity) this involves looking if the matrix

$$\rho_P = \begin{pmatrix} \alpha & 0 & 0 & 0 \\ 0 & \beta & \gamma & 0 \\ 0 & \gamma & \beta & 0 \\ 0 & 0 & 0 & \alpha' \end{pmatrix}. \tag{2}$$

has negative eigenvalues. If it does, the state is entangled; otherwise [6] it is not. The state (1) is entangled if and only if $\gamma > \beta$. The reader will easily convince

himself by inspecting the tomographic data in [1] that this is never the case for any of the measured states.

For the case at hand one can show that the measured states are all unentangled even without the Peres criterion. For the sake of simplicity we take $\alpha = \alpha'$ and $\beta = \beta'$. In this case the matrix in Eq. (1) can be written as [7]:

$$\begin{aligned} \rho \quad = \quad & (\alpha - \gamma)\big(\rho_{\hat{z}} \otimes \rho_{\hat{z}} + \rho_{-\hat{z}} \otimes \rho_{-\hat{z}}\big) + (\beta - \gamma)\big(\rho_{\hat{z}} \otimes \rho_{-\hat{z}} + \rho_{-\hat{z}} \otimes \rho_{\hat{z}}\big) \\ & + \gamma\big(\rho_{\hat{x}} \otimes \rho_{\hat{x}} + \rho_{-\hat{x}} \otimes \rho_{-\hat{x}} + \rho_{-\hat{y}} \otimes \rho_{\hat{y}} + \rho_{\hat{y}} \otimes \rho_{-\hat{y}}\big) \end{aligned} \tag{3}$$

where the single qubit state $\rho_{\hat{n}} \geq 0$ is defined by

$$\rho_n = \frac{\mathbb{I} + \hat{n} \cdot \vec{\sigma}}{2} \tag{4}$$

$\vec{\sigma} = (\sigma_x, \sigma_y, \sigma_z)$ is the vector of Pauli matrices; $\hat{n}$ a unit vector in three dimensions and $\mathbb{I}$ the identity matrix. Evidently, ρ is a convex combination of product states for all $\beta \geq \gamma$ and $\alpha \geq \beta$ and agrees with the definition of a separable (unentangled) state. Since this is the case for the tomographic data for all the dots in [1] none of them produced an entangled state.

As the above analysis shows, the emergence of off-diagonal terms for dots with "which path" spectral ambiguity is not a satisfactory evidence for entanglement as the authors of [1] claim. The authors also subject their data to an additional tests of entanglement. This test involves further processing of the data that discards a significant part of the photon counts. Our analysis applies the definition of entanglement (alternatively the Peres criterion) to the quantum state as measured by quantum tomography. Thus any correct test for entanglement must agree with our conclusions when applied to the same data.

In conclusion, either the quantum tomography data of the dots studied in [1] is reliable and then none of the quantum states produced in the experiment corresponds to entangled photons; or the tomography data are not of sufficient quality and no definite conclusion can be drawn from the experiment.

Note added: After the above criticism was communicated to the authors of [1], they have posted a new paper on the arXiv preprint server, describing results of a new experiment. In this preprint they refer to [1] as the first demonstration of emission of entangled photon pairs from quantum dots. In light of the above, this claim is false. In fact, the first correct demonstration can be found in [8].

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References

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[7] The following command lines compute the tensor product of matrices in Mathematica:

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Needs["LinearAlgebra`MatrixManipulation`"]
KroneckerProduct[a_?SquareMatrixQ, b_?SquareMatrixQ]:=
BlockMatrix[Outer[Times,a,b]]
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[8] N. Akopian, N.H. Lindner, E. Poem. Y. Berlatzky, J. Avron, D. Gershoni, D.B. Gerardot and P.M. Petroff, Entangled photon pairs from a semiconductor quantum dot, quant-ph/0512048